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Research Article

Classifying climate change adaptation measures for ski areas and ski lifts – The case of Bavaria, Germany

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ABSTRACT

Ski tourism is facing increasing challenges due to climate change and adapting to these changes is particularly imperative for ski areas at lower altitudes. With snowmaking as the primary adaptation for ski areas, knowledge on alternative strategies and their effectiveness to address future climate risks is limited. Furthermore, it remains unclear to what extent, and by which types of ski areas, these alternatives are implemented, and what factors drive or hinder their adoption. To address these research gaps on transformational adaptation of ski areas, we employ a mixed-method approach, integrating quantitative survey data (n = 83) and qualitative interview insights (interviews with seven ski area operators) on the case of ski areas and ski lifts in Bavaria (southern Germany). We develop a framework to categorise adaptation measures according to their depth of intervention from inaction to transformation, assess their current implementation status, and group 240 Bavarian ski areas into five distinct clusters.

Our findings reveal differences among ski area clusters regarding implemented and planned adaptation measures. The clusters comprising smaller, snow-unreliable ski areas exhibit a significant proportion of ski areas with little to no adaptation measures. However, interview insights demonstrate that their unique organisational structures may protect them from severe climate-induced losses, which the literature identifies as an expected consequence of inaction in response to climate change. In contrast, for larger, more snow-reliable ski areas in Bavaria, we observed a relatively strong reliance on coping measures and, unlike findings from other studies, a moderate to strong implementation of transformative adaptations, such as product diversification and year-round operation. Our paper contributes to the literature by integrating the concept of transformation from climate change research to research on ski areas, thereby conceptualising climate change adaptation measures and their potential capacity to address future climate change risks.

Management implications: Considering the urgent need for climate adaptation in Bavaria's low-altitude ski areas, this paper highlights the heterogeneity of the region's ski areas and ski lifts, underscoring significant variations in their size and climatic conditions. By introducing a framework for categorising adaptation measures, it demonstrates that adaptation measures for ski infrastructure vary in how much they modify existing systems.

The analysis of currently implemented or planned adaptation measures among Bavarian ski areas and ski lifts reveals significant differences between the surveyed clusters regarding the types and extent of adaptation efforts. Understanding the diversity of ski infrastructure in Bavaria, the varying levels of intervention associated with different adaptation options, as well as the empirical analysis of the status quo of climate change adaptation in Bavarian ski areas and ski lifts provides ski area managers and other practitioners with a more nuanced perspective. This enables them to make informed strategic decisions regarding adaptation options and to act from a position of strength and knowledge, rather than out of necessity.

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1. Introduction

Tourism and outdoor recreation are of great significance in the Alps, with winter sports tourism and the associated ski infrastructure, such as ski areas and ski lifts, contributing considerably to the economy in many Alpine destinations (Tranos & Davoudi, 2014), forming the image of many mountain regions (Bavarian State Ministry of the Environment and Consumer Protection., 2021), and strengthening local identities, traditions and practices (Hetzenauer et al., 2022). Nevertheless, the high dependence of ski areas on climate conditions renders them susceptible to challenges arising from the accelerated pace of climate change in the Alpine region (IPCC, 2023b). Expected significant reductions in snowfall and declining numbers of days below 0 °C, pose a risk, particularly for lower-altitude and less snow reliable ski areas (Dworak et al., 2021; Gobiet et al., 2014; Morin et al., 2021). Therefore, adapting to climate change is imperative for ski destinations at lower altitudes, such as in Bavaria, Germany, to minimise adverse effects (Bausch & Gartner, 2020; Witting & Schmude, 2019). Yet, research on tourism, climate change, and adaptation to climate change remains less advanced compared to many other sectors and does not seem to be a major priority on the tourism academy's research agenda (Scott & Gössling, 2022).

Although there is a growing body of literature on climate change adaptation in general, there is a lack of knowledge about the actual level of implementation of adaptation actions, especially regarding responses within the private sector (Berrang-Ford et al., 2021; Sietsma et al., 2021). To date, research on climate change adaptation in ski tourism research has predominantly concentrated on supply-side adaptation with a focus on snowmaking (Steiger et al., 2019), snowmaking capacity, and increasingly challenging conditions for snowmaking (Berard-Chenu et al., 2023; François et al., 2023; Gerbaux et al., 2020; Knowles, 2019; Scott & Gössling, 2022). Only in a few cases (e.g. Hetzenauer et al., 2022; Schlegel & Schuck, 2024), the literature has thereby addressed the significant differences in size and the differing importance of ski areas for overnight tourists, day visitors, and the local population.

The adaptation behaviour of the demand side is complex due to the high flexibility and location independence of guests (Rutty et al., 2015; Scott et al., 2012). Compared to supply-side adaptation, climate change-induced adaptation behaviour of the demand side has received less attention in tourism research (Steiger et al., 2019; Witting et al., 2021). However, the literature suggests that the adaptation behaviour of the demand side directly impacts the supply side: guests' ability to change their travel time, location, or activity in response to unfavourable conditions (e.g. snow shortages) compels ski areas to adopt adaptation measures. These measures may include merging ski areas to meet guests' preference for larger ski areas (Falk, 2017; Pröbstl-Haider & Mostegl, 2016; Unbehaun et al., 2008) or investing in snowmaking capabilities, both aiming to remain competitive and prevent guests from shifting to other locations (Bausch et al., 2019; Trawöger, 2014). Nevertheless, evidence shows that snowmaking is a questionable long-term adaptation measure for most low-altitude ski areas (Cholakova & Dogramadjieva, 2023; Mayer & Steiger, 2013; Scott et al., 2024): Snowmaking is becoming less efficient when temperatures rise (Scott et al., 2020) and higher temperatures present increasing challenges for generating sufficient and cost-effective snow (Steiger & Scott, 2020). Moreover, the viability of snowmaking as an adaptation strategy is highly dependent on location (Scott et al., 2024). However, research about adaptation options beyond snowmaking (e.g. other snow management activities, expansion towards more snow-reliable terrain, or strategic and management solutions) remains rather limited (Dannevig et al., 2021; Scott & Gössling, 2022).

Furthermore, knowledge gaps exist regarding the extent to which such adaptation measures beyond snowmaking are implemented and by which type of ski area. Research, particularly on ski infrastructure such as ski areas and ski lifts, still lacks a conceptual approach for evaluating different adaptation measures to identify those that effectively address future climate risks (Tourism Panel on Climate Change, 2023). In this context, the climate change adaptation literature often refers to two approaches, which are central to the current state of research on adaptation assessment (Magnan et al., 2020, p. 167 ff.): the "Incremental vs. Transformational Divide" and the "Maladaptation-Adaptation Continuum". Only recently, snowmaking was subject to maladaptation assessments (Knowles et al., 2024; Scott et al., 2024). However, studies addressing transformational adaptation from a conceptual viewpoint are still rare in ski tourism research, as well as in the broader field of climate change adaptation research (Fedele et al., 2019; Kates et al., 2012; IPCC, 2023c).

Therefore, this study contributes to the literature by addressing the research gap on transformational climate change adaptation and applying the concept of transformation from climate change studies into research on ski infrastructure. Thus, we advance the following research questions in this supply-side study:

RQ1: To what extent and by whom are different types of climate change adaptation measures, including and beyond snowmaking, employed in Bavarian ski areas, and which patterns are identifiable?
RQ2: What is the current state of development of transformative adaptation, and what factors impede or facilitate its advancement in the future?

We analyse these research questions using a mixed-methods approach, which integrates quantitative survey data with qualitative interviews. Bavaria, the largest German state, was selected as a case study due to its long tradition in winter sports tourism, the relatively high number of ski areas and their relatively low altitude, which renders them particularly susceptible to the effects of climate change (Mayer & Steiger, 2013).

This paper is structured into several sections: an overview of state-of-research on adaptation in research on ski areas and ski lifts is followed by a description of the case study region and the methods used. After presenting the results, which include the categorisation of adaptation measures, the clustering of Bavarian ski areas, an analysis of the current implementation status of adaptation measures, and an examination of drivers and barriers to transformative adaptation, the conceptual and practical implications and limitations are discussed.

2. Adaptation to climate change in ski tourism research: An overview

2.1. Climate change adaptation in ski areas beyond snowmaking

Climate change adaptation is understood as a dynamic development rather than a status (Pelling, 2011) and in this study, we use the IPCC's definition of adaptation as a "process of adjustment to actual or expected climate and its effects" (Klein et al., 2015, p. 1758). Despite the rapidly growing body of adaptation research, only a small portion of the literature reports on implemented measures (Berrang-Ford et al., 2021; Sietsma et al., 2021).

In the past, research about climate change adaptation in ski areas has predominantly focused on the installation and intensification of snowmaking facilities, along with associated snow preservation activities. These include snow farming (both artificial and natural snow) (Fischer et al., 2016; Mayer & Abegg, 2024), improved weather forecasting to optimise snow-making timing (Scott & McBoyle, 2007), monitoring of snow depth on ski slopes for more efficient snowmaking (Steiger et al., 2021), and grooming of ski slopes (Haanpää et al., 2015). Such strategies represent the most significant and widely implemented adaptation measures within the winter tourism industry (Dannevig et al., 2021; Haanpää et al., 2015).

Adaptation measures aiming at conserving and protecting natural or artificial snow include the construction of roofs over skiing slopes to create a semi-indoor arena (Aall et al., 2016) and the reforestation of nearby areas to shade the slopes and slow the rate of snow melting (Haanpää et al., 2015). If local regulations and the topography permit, ski areas can expand towards higher altitudes or north-facing slopes (Cholakova & Dogramadjieva, 2023), construct indoor-ski arenas with controlled climate conditions (Schmude, 2007), connect with more snow reliable slopes within the same destination or even shift to other destinations by developing new, more snow-reliable ski areas (Falk, 2013; Schmude & Berghammer, 2015).

Some adaptations overlap with initially business-driven decisions. These decisions result in adaptations by compensating for potential financial losses due to climate change through intensification strategies, such as increasing the utilisation rate and lift ticket sales (Abegg et al., 2017; Dannevig et al., 2021). This category includes measures such as the installation of floodlights to enable nocturnal skiing. Nocturnal skiing extends the useable hours of ski slopes under favourable climate conditions, thereby enhancing overall benefits and lift ticket sales (Cholakova & Dogramadjieva, 2023). Additionally, financial incentives, such as dynamic pricing (Steiger et al., 2024) or the offering of discounts and refunds (Dannevig et al., 2021; Scott & McBoyle, 2007), can help maintain ski ticket sales even under suboptimal snow conditions.

Adaptation measures like product diversification or year-round operation can reduce dependence on snow and create additional value through snow-independent activities (Dubois & Ceron, 2006; Scott & McBoyle, 2007). Although these measures have been recognised and acknowledged as important already in the past (e.g. Abegg, 1996; Elsasser & Bürki, 2002), empirical evidence on these measures in a more comprehensive manner remains limited, particularly when compared to the extensively researched measure of snowmaking (Dannevig et al., 2021; Scott & Gössling, 2022). Bausch and Unseld (2018) demonstrate that the non-skiing market of winter holidaymakers, comprising groups seeking relaxation in winter landscapes and engaging in lighter sporting activities, represents a significant and largely untapped segment and a chance for future development.

Another approach that has seen little use so far in the Alps is artificial or hybrid ski mats (Aall et al., 2016), which imitate the feeling of skiing on real snow (Kühne, 2023). Another measure is cloud seeding, an agricultural technology typically applied to irrigate crops during the summer months. It can be employed to generate additional precipitation at ski areas and has been utilised to try to increase snowfall. Nevertheless, this technique remains controversial and unpopular (Scott & McBoyle, 2007).

A systematic overview of the conceivable measures is provided in the appendix (Table A1).

2.2. The concept of transformation

Magnan et al. (2020) distinguish two conceptual advances that represent key research frontiers in climate change adaptation research, aimed at aiding decision-makers in designing and implementing specific adaptation policies and actions, especially when a broad range of theoretical options is available. These concepts seek to answer the question of what kind of adaptation measures are the most effective: the 'Adaptation-Maladaptation Continuum', and the 'Incremental vs. Transformational Adaptation Dichotomy' (Magnan et al., 2020). Recently, the concept of (mal)adaptation was applied to ski tourism by evaluating snowmaking (Scott et al., 2024), applying several maladaptation criteria based on Barnett and O'Neill (2010). Knowles et al. (2024) discussed snowmaking in the context of maladaptation in terms of water use, energy consumption, and greenhouse gas emissions. These two studies focus exclusively on snowmaking and conclude that the assessment is highly location- and resource-dependent, with a multitude of variables influencing the outcome. Thus, a maladaptation assessment has already been applied in ski tourism research, albeit exclusively in the snowmaking context. In contrast, the concept of transformation has yet to be applied in research on different climate change adaptation measures in ski areas. Magnan et al. (2020) further call for specifically assessing the effectiveness of individual adaptation measures, which remains a considerable gap in research on ski areas.

However, the notion of transformation and its underlying theory, which involves a time component either as "short-term perspective" or finding ways to reduce risk in the "long-term" (Magnan et al., 2020, p. 167), are not entirely unfamiliar to the tourism literature: A review reveals that studies have adopted the idea of 'incremental vs. transformative' adaptation but fail to apply a systematic concept. Most studies distinguish a dichotomy of short- and long-term adaptation measures and place snowmaking and year-round operation at the opposite poles, neglecting other adaptation measures (Cholakova & Dogramadjieva, 2023; Haanpää et al., 2015; Hopkins, 2014; Hopkins & Maclean, 2014; Pickering & Buckley, 2010). Salim et al. (2021) identified eight climate change adaptation strategies, including transformational projects, in the context of glacier tourism. Aall et al. (2016, p. 218) position adaptation strategies in winter tourism along a spectrum from "adjustments to transformative efforts". That said, although the concept of transformation is not new in the tourism literature, it has yet to be explored in a comprehensive, conceptual manner. In section 2.3, we therefore suggest a framework to categorise the earlier identified potential adaptation measures.

Findings from ski tourism studies further illustrate that ski area operators tend to prioritise near-term or incremental adaptation strategies, such as snowmaking, which maintain the status quo and fail to consider long-term measures like the transformative development of year-round operation or product diversification (IPCC, 2023b; Cholakova & Dogramadjieva, 2023; Haanpää et al., 2015; Hopkins, 2014; Knowles, 2019; Pickering & Buckley, 2010). The preference for short-term fixes arises from multiple factors, including scepticism about the reality of adverse climate change impacts, a focus on immediate operational and economic gains, and faith in technology's ability to mitigate climate risks, all of which complicate the implementation of long-term adaptation strategies and reinforce resistance to altering the status quo business model (Abegg et al., 2017; Haanpää et al., 2015; Hopkins, 2014; Steiger et al., 2019).

2.3. Framework for categorising adaptation measures

Since there is no universally applicable classification of adaptation actions and distinctions between them can be ambiguous (Goldstein et al., 2019; Kates et al., 2012), in this study we propose an own framework for classifying adaptation measures in ski areas and ski lifts in Bavaria and assign each earlier identified adaptation measure to a category within our framework (Table 1). Our framework categorises different types of adaptation based on the depth of their intervention and proposes four distinct types of measures: inaction, coping measures, transition, and transformation. However, this classification is not intended to assess the suitability, efficacy, or applicability of the respective adaptation measures. Instead, it aims to highlight the differences between these potentially applicable measures in terms of the depth of intervention, the magnitude of change, and the potential to address future climate change risks.

We base our framework primarily on the adaptation pathways framework by Pelling (2011), and complement it with key contributions from Schipper (2020), Kates et al. (2012), and Fedele et al. (2019).

Inaction refers to the failure to respond to a changing climate (Fedele et al., 2019). Such inaction will eventually lead to increased vulnerability to climate change and can be considered maladaptive, as noted by Schipper (2020). According to Fedele et al. (2019), this lack of response frequently results in significant losses. Ski areas, which do not apply any adaptation measure, fall into this category.

Adaptation measures categorised as coping measures often involve maintaining the status quo and are characterised by reactive behaviour (Fedele et al., 2019). Such approaches focus on repairing damage rather than proactively transforming systems. While these measures help cope with current challenges, they may not effectively address or prevent future climate risks. In the context of ski areas and ski lifts, coping

Table 1
Potential adaptation measures for ski area and ski lift management and corresponding types of climate change adaptation.

Adaptation type	Inaction	Coping measures	Transitional adaptation	Transformative adaptation
Brief description	No adaptation measures.	Reactive solutions; repairing damage; maintaining the status quo.	Modification of systems; no change of the existing regime; remaining vulnerable.	Fundamental changes to the system; aims to reduce the root causes of vulnerability.
Examples[a]	–	Reforestation Roofing over slopes Snow farming Technical snowmaking Cloud seeding Slope maintenance Weather forecasting Financial incentives Night skiing	Artificial ski mats Indoor ski facilities Connecting ski areas Expanding ski areas	Product diversification Year-round operation

[a] The categorised measures vary significantly in their suitability, effectiveness, and applicability, with their performance differing substantially across various ski areas. The table above categorises these measures based on the previously introduced classification of adaptation actions based on the depth of their intervention and is not intended to serve as an evaluation of the suitability of each measure.
Source: based on Pelling (2011), Kates et al. (2012), Fedele et al. (2019), and our own categorisation of examples derived from the literature on ski area adaptation.

measures address damage caused by insufficient snow precipitation or accelerated snowmelt, focusing on the generation of artificial snow or management of snow (e.g. snowmaking, snow farming, cloud seeding, slope maintenance (including snow measurement), weather forecasting; see Table A1 for a detailed description of the specific measures) or to slow down snowmelt (reforestation, roofing, weather forecasting). Financial measures and night skiing aim to mitigate losses from reduced demand due to suboptimal climate conditions and maximise usage rates during favourable conditions. Overall, these measures maintain the existing ski infrastructure system reliant on snow without fundamentally altering it.

Transitional adaptation measures refer to approaches characterised by incremental changes rather than transformative shifts (Pelling, 2011). Incremental adaptation involves small-scale adjustments to existing practices for managing climate impacts, as outlined by Kates et al. (2012). Pelling (2011) describes incremental adaptation as an intermediary engagement level focused on modifying governance regimes without fundamental alterations. Compared to reactive coping measures, these measures tend to be more anticipatory (Fedele et al., 2019). For the case of skiing, artificial ski mats and indoor skiing facilities enable skiing under controlled conditions, decreasing dependence on natural snow. However, these measures do not fundamentally alter the traditional skiing experience; instead, they introduce new dependencies, such as reliance on electricity for indoor ski facilities, and generate additional issues, such as plastic abrasion in the case of ski mats (Kühne, 2023). Connecting or expanding ski areas also falls into this category, as these actions postpone current issues by relocating operations to more snow-reliable altitudes or orientations. Yet, they remain vulnerable to the same threats as climate change continues to progress over time.

Transformative adaptation is a profound change that shifts a system's fundamental structure, creating new interactions within social-ecological systems. Its goal is to address the root causes of vulnerability to climate change (Fedele et al., 2019; Pelling, 2011). Kates et al. (2012) note that this transformation is broader in scale and intensity and introduces innovations to a region or resource system. It is particularly urgent in vulnerable regions or sectors like ski tourism, where adapting to climate change requires significant, systemic changes (Fedele et al., 2019; Kates et al., 2012; IPCC, 2023c). The measures categorised as transformative include product diversification and year-round operation. Both strategies aim to decouple ski areas from their fundamental dependence on snow availability. Product diversification (e.g. providing outdoor-based activities such as winter hiking, or wellness attractions) involves introducing alternatives to skiing, not only when snow conditions are suboptimal, while year-round operation shifts operations to be less reliant on seasonal snow and helps distribute income more evenly throughout the year. Both strategies typically engage the entire region, involve interactions among various stakeholder groups and foster innovations throughout the destination, such as a shift towards outdoor-based or wellness-based tourism experiences, moving away from the vulnerable ski tourism model (IPCC, 2023a; Cholakova & Dogramadjieva, 2023; Dubois & Ceron, 2006; Hopkins, 2014; Scott & McBoyle, 2007).

3. Materials and methods

3.1. Case study

Bavaria, the largest and southernmost state of Germany, is characterised by a high proportion of small to medium-sized ski areas (Steiger & Abegg, 2018) at relatively low altitudes (Abegg et al., 2017; Bausch, 2019; Mayer & Steiger, 2013; Scott et al., 2012). The relatively flat and wide valley bottoms are often situated at altitudes of 750 m or below. Many of the alpine mountains are either very rocky or have steep, forested hillsides (Bausch, 2019). Most ski areas and ski lifts are concentrated in the Bavarian Alps in the south of Bavaria and the Bavarian Forest in the east (Fig. 1).

The Bavarian ski areas vary significantly in size: Approximately 50 % of the 240 ski areas consist of no more than one or two lifts. In the larger ski areas, the network of slopes typically extends no more than 20–30 km (OpenSkiMap.org, 2024; Skiresort.de, 2024). The ski area Zugspitze represents the only ski area situated (in small parts) on a glacier. Due to their relatively low altitude, ski areas in Bavaria are particularly vulnerable to climate change (Mayer & Steiger, 2013; Morin et al., 2021; Steiger, 2013).

Nevertheless, winter sports have a long tradition in Bavaria. Day-trippers, short-stay holiday tourists, and visitors from the metropolitan area of Munich form a large target group for Bavarian ski areas (Bausch, 2019). Tourism plays an important role in Bavaria's economy, and, like many other winter sports destinations in the European Alps, ski tourism and its associated ski infrastructure are key factors in attracting visitors during the winter months (Bätzing, 2017). For many visitors, the opportunity to practice winter sports is still a decisive factor when choosing their winter holiday destination (Bausch et al., 2017). The significance of Bavarian ski areas for tourism varies widely, ranging from very small-scale operations primarily serving day-tripping families and beginners from nearby communities to larger ski areas that attract overnight visitors. Unfortunately, with a few exceptions, data on first entries and visitor frequentation for mountain ropeways and ski areas in the Bavarian Alps are largely unavailable (Mayer & Steiger, 2013).

A characteristic of Bavarian ski areas, particularly those at popular mountains in the Bavarian Alps and the Bavarian Forest, is that many were not initially built for ski tourism but rather as transportation facilities to improve mountain accessibility for the public and were later

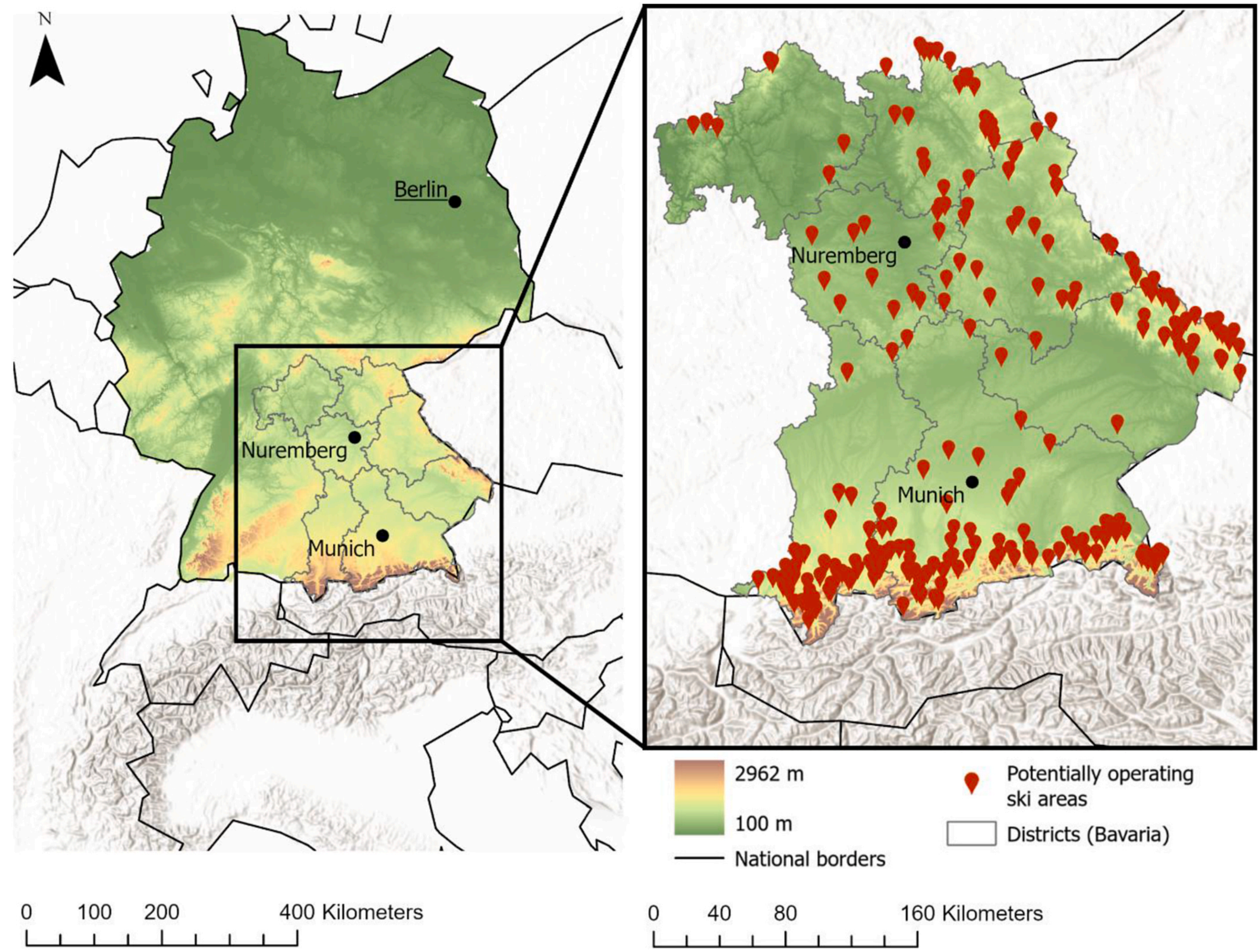

Fig. 1. Potentially operating ski areas and ski lifts in Bavaria, winter season 2023/24
Source: based on OpenSkiMap.org (2024), Skiresort.de (2024), BKG (2024), ESRI (2013).

adapted for skiing. Today, the focus seems to be shifting once again: According to the German association of cable cars and drag lifts, 80 % of their listed ropeways are operated in summer and winter with an increasing focus on serving as year-round attractions for visitors, offering panoramic views and activities such as hiking in spring, summer and fall, and skiing in winter (Verband Deutscher Seilbahnen und Schlepplifte e.V, 2024). Moreover, the Bavarian government subsidises the modernisation of ski lifts since 2009, with an increasing focus on supporting projects which include the potential for year-round use, requiring that the measure also supports summer tourism (Bavarian State Ministry for Food, Agriculture, Forestry, and Tourism, 2024). However, an evaluation of the funding programme revealed that, at the time of the study, only about half of the subsidised cable cars operated during the summer. Consequently, the objective of enhancing year-round tourism through the programme was only partially achieved (Seibold et al., 2022).

3.2. Study design, data and study methods

This study employs a mixed-methods approach to investigate the climate change adaptation measures implemented by ski area and lift operators in Bavaria. The combination of quantitative and qualitative data allows for the collection of data from a substantial number of ski areas in Bavaria, complemented by in-depth insights from face-to-face interviews.

Utilising both structural data and climate data, we carry out a cluster analysis to group all Bavarian ski areas and ski lifts. For the structural input variables, we collected data from OpenSkiMap.org (2024), Skiresort.de (2024) and from the Bavarian State Office for Statistics (2025) on all existing ski areas in Bavaria that predominantly serve Bavarian terrain. We identified 240 ski areas that potentially provided skier transportation service during the winter season of 2023/24. This includes areas connected to groomed slopes as well as those servicing only unsecured ski terrain or ski routes. Lifts that do not offer maintained slopes but transport freeriders or ski tourers were included in our dataset only if the lift operator actively promotes its transport services, for example on their website. Our analysis also included single lifts, which we considered separate ski areas if they were distinguishable from other ski areas and operated by a different operator. For each ski area or ski lift, we gathered data on their location, minimum and maximum altitudes of the lifts, elevation difference, total length of all slopes, total number of ski lifts, capacity in passenger per hour, winter tourism overnight stays, and winter tourism intensity of the municipality where the ski area or ski lift is located. From all the collected structural data, we decided to incorporate the total number of ski lifts as a variable for the subsequent clustering, as it serves as an indicator for the size of the ski area.

To enhance the dataset with information on climate change impacts on the ski areas, we incorporated data from the Copernicus Institute Mountain Tourism Meteorology and Snow Indicators (MTMSI) dataset by Morin et al. (2020). This dataset provides pan-European information on snow reliability under past and future climate conditions with and without snow management practices such as grooming or snowmaking. It includes 39 indicators available for all mountain regions in Europe at the NUTS-3 level and 100-m elevation intervals. For our clustering, we chose to incorporate data on total winter season snowfall amounts (in centimetres), as this variable informs about the altitude over which the ski area extends as well as the amount of snow precipitation on the given altitude stretch. To collect the data on snow precipitation for a ski area that spans several hundred meters, we computed mean values based on data gathered at 100-m intervals. For instance, in the case of a ski area extending from 730 m to 1230 m, data were gathered at each 100-m increment from 700 m to 1200 m, and the average value was subsequently calculated. Our analysis focuses on near-future climate conditions (2021–2040) to align with the time frame typically used by ski area management when making decisions, under a moderately ambitious climate change mitigation scenario (RCP 4.5). We opted to use only RCP 4.5 in order to simplify the cluster analysis and focus on a scenario that is neither characterised by optimistically declining emissions nor by a pessimistic peak-emission development (IPCC, 2023c).

By clustering the Bavarian ski areas, we acknowledge the heterogeneity of Bavarian ski areas according to their sizes and climatic future (Schlegel & Schuck, 2024). We clustered our data using the K-means algorithm in the statistical open-source software R (with functions from packages *stats, readxl, factoextra, dplyr, corrplot*). K-means is a widely used method for cluster analysis due to its relative simplicity and ease of implementation (Lund & Ma, 2021). Prior to performing any analysis, we scaled our data to ensure that all features were brought to a comparable scale so that they are equally weighted in the clustering process. In K-means clustering, each observation is assigned to one of a k-number of clusters, based on their distance to the cluster's mean, using the Euclidean distance (Johnson & Wichern, 1998; Kanungo et al., 2002). The number of clusters is not predefined; therefore, we employed the Elbow method to determine the optimal number of clusters. The optimal number should be chosen such so that adding an additional cluster does not lead to a significant reduction in the variance of the data (Bholowalia, 2014).

To collect data on the status quo of climate change adaptation in Bavarian ski areas, we developed a questionnaire and distributed the link to the online survey via email to all 240 ski area and ski lift operators in October and November 2023. We achieved a response rate of approximately 35 %, with 83 completed and valid returned questionnaires. In the questionnaire, we requested information about the name and location of the ski area, and the management structure (private company; managed by the municipality; managed by an association; or other). To assess the extent to which adaptation measures have already been implemented or are planned by different ski areas (RQ1), we provided each participant with a list and brief descriptions of possible adaptation measures for ski areas (Table A1). We then inquired whether the ski area had already implemented each measure or intends to do so in the future. We descriptively analysed the proportion of ski areas that had already implemented or planned a specific measure.

In addition to the quantitative fieldwork, seven qualitative interviews with ski area operators across all clusters were conducted from April to June 2024. The interviews aimed at validating our results and gaining information on the reasons for the implementation or rejection of transformative adaptation measures in the respective ski area (RQ2). The participants had given their consent in the questionnaire to take part in a follow-up interview and were selected to represent each cluster at least once. These interviews were conducted via telephone, video call, and in person. A detailed list of all interview participants can be found in Table A2. All interviews were semi-structured but allowed for spontaneous questions based on the flow of the conversation (Döring & Bortz, 2016). All interviews were audio-recorded and transcribed prior to the analysis. Qualitative information from these in-depth interviews was manually coded based on the theory of qualitative content analysis (Mayring, 2015) and subject to a qualitative analysis using MaxQDA (VERBI Software, 2021). An initial deductive coding framework, based on the different types of adaptation, was applied and progressively supplemented with new inductive codes and subcodes throughout the process.

4. Results

4.1. Identifying clusters of Bavarian ski areas and ski lifts

We apply a cluster analysis to Bavarian ski areas to analyse the extent and depth of implementation of different types of climate change adaptation measures and to identify patterns. Using the Elbow method, we identified five as the optimal number of clusters. The five distinct clusters (Table 2) are based on the structural variable 'total number of ski lifts' and the climate variable 'total winter season snowfall amounts' (Fig. 2). We have assigned the following names to the clusters to facilitate their distinction: Nostalgic Lifts, Shadow Existence, Struggling Lifts, Underdogs and Big Player.

The Nostalgic Lifts and Shadow Existence cluster collectively comprise more than 75 % of all ski areas, yet they account for only 25 % of the total ski slope length. Both clusters exhibit the lowest average numbers of winter overnight stays in ski area municipalities, with the Nostalgic Lifts cluster accounting for 20.9 % and the Shadow Existence cluster 25.7 % of all winter overnight stays in ski area municipalities (Table 2). Moreover, both clusters are characterised by very low altitudes and a small scale, typically operating only one or a few lifts with limited capacity. Many Shadow Existence lifts are located within traditional ski regions near larger, more prominent ski areas, distinguishing them from the Nostalgic Lifts, which are distributed more widely across the country, including relatively flat regions (Fig. 3). Both clusters are generally snow-insecure, although the Shadow Existence cluster exhibits a slightly higher snow-reliability compared to the Nostalgic Lifts. Based on interviews, it is evident that these lifts would not be able to function without community subsidies, volunteers, and knowledge-sharing within the community. They are typically operated by the local community or sports associations, driven by individuals who are passionate about skiing and committed to preserving the tradition of skiing in their home villages (Interviews A and C).

In contrast, the Struggling Lifts have developed a certain level of infrastructure and capacity that requires a higher level of management to maintain, as these dimensions can no longer be managed by volunteers alone (Interviews D and E). However, they also face challenges due to insufficient snowfall, with snow reliability indicators falling only in the lower middle range.

Ski areas in the Underdogs cluster are smaller compared to the Struggling Lifts. However, they are relatively snow reliable due to their location at higher altitudes, higher amounts of snow precipitation, and consecutive periods of time of which the snow cover exceeds a minimum of 30 cm.

The Big Players are front-runners in infrastructure and snow reliability. Although they represent less than 3 % of all ski areas in Bavaria, they account for 32 % of the total ski slope length and contribute 24.2 % of the total winter overnight stays in municipalities with ski areas or ski lifts (Table 2).

The tourism key figures indicate that municipalities in Bavaria without a ski area or a ski lift (excluding independent cities from that analysis) exhibit, on average, a number of 21,980 winter overnight stays and a mean tourism intensity of 3772 per 1000 inhabitants. On average, municipalities with a ski area or ski lift exhibit both significantly higher numbers of winter overnight stays (t-value -4.178, $p < .001$) and greater winter tourism intensity (t-value -3.799, $p < .001$) compared to other Bavarian municipalities that do not host such infrastructure. This pattern holds across all five clusters. However, this does not imply a

Table 2
Clustering results for ski lifts and ski areas in Bavaria.

	Nostalgic Lifts	Shadow Existence	Struggling Lifts	Under-dogs	Big Player
Total number of ski areas (n)	115	69	20	26	10
Structure					
Average number of ski lifts *[lifts]*	1.4	1.7	6.3	3.0	12.9
Median [lifts]	*1.0*	*1.0*	*6.0*	*3.0*	*13.0*
Standard deviation [lifts]	*0.8*	*0.9*	*1.3*	*1.6*	*2.4*
Average length of slopes [km]	.8	1.4	7.0	7.6	24.8
Median [km]	*0.4*	*0.9*	*6.3*	*7.2*	*25.4*
Standard deviation [km]	*1.6*	*1.5*	*4.9*	*6.4*	*11.7*
Average max. elevation [m]	630	886	1241	1506	1687
Median [m]	*620*	*885*	*1230*	*1463*	*1572*
Standard deviation [m]	*160*	*167*	*267*	*289*	*439*
Average min. elevation [m]	563	758	809	954	1012
Median [m]	*570*	*775*	*822*	*909*	*950*
Standard deviation [m]	*140*	*104*	*115*	*200*	*347*
Future climate conditions (RCP4.5; 2021–2040)					
Average number of days with natural snow depth above threshold (30 cm)	7	38	65	95	96
Median	*5*	*36*	*65*	*93*	*97*
Standard deviation	*5*	*14*	*12*	*17*	*17*
Average sum of winter snowfall amount [cm]	93	211	301	429	422
Median [cm]	*88*	*206*	*290*	*422*	*431*
Standard deviation [cm]	*30*	*40*	*55*	*65*	*69*
Winter season tourism key figures (November 2023–April 2024)					
Mean number of winter overnight stays (ski area municipalities)[a]	25,378	47,811	78,537	74,846	205,528
Share of overall winter overnight stays (in ski area municipalities)[a]	20.9 %	25.7 %	16.5 %	12.7 %	24.2 %
Mean winter tourism intensity (ski area municipalities, per 1000 inhabitants)[a]	5279	13,897	23,530	20,181	64,707

[a] To avoid double counting, when two or more ski areas from different clusters are located within the same municipality, we aggregated the number of lifts and total slope length and assigned the municipality to the highest-ranking cluster. Source: calculation based on data on ski areas from OpenSkiMap.org (2024) and Skiresort.de (2024) for the winter season 2023/24, climate data by Morin et al. (2020), and tourism key figures from the Bavarian State Office for Statistics (2025).

causal relationship between these tourism indicators and the presence of a ski area or ski lift, nor does it account for visitor numbers from day trippers or the local population, for which data is unavailable.

A Pearson correlation analysis between ski lift infrastructure and tourism key indicators reveals significant relationships between the length of slopes and winter tourism overnights ($r = .434$, $p < .001$) as well as tourism intensity ($r = .468$, $p < .001$). Similarly, the number of ski lifts shows a significant correlation with winter overnight stays ($r = .436$, $p < .001$) as well as tourism intensity ($r = .403$, $p < .001$).

4.2. Cluster analysis

4.2.1. Operational structures per cluster

Table 3 presents the operational structures of the surveyed ski areas, organised according to the clusters.

In contrast to the often municipality- or association-operated ski areas from the Nostalgic Lifts and Shadow Existence clusters, the Underdogs, Struggling Lifts and Big Players are primarily organised as companies and constitute only 23 % of all Bavarian ski areas. However, in some cases, the municipality operates through a privately organised business structure not represented by this data. We achieved a relative response rate per cluster ranging from 23 % (Underdogs) to 90 % (Big Player).

4.2.2. Implemented and planned adaptation measures per cluster and type of adaptation

This section presents combined findings from the survey and the interviews (see Table A2). The findings indicate that the implemented respectively planned adaptation measures differ between the clusters. Table 4 shows the proportion of surveyed ski areas in each cluster that have already implemented or planned a specific climate change adaptation measure across the categories of coping, transitional, and transformational measures. However, it is important to note that these adaptation measures not only differ in their depth of intervention but also require varying levels of investment and time, differ significantly in effectiveness, and vary in feasibility and field of application.

4.2.2.1. Inaction. At least one climate change adaptation measure was implemented by each of the surveyed ski areas from the Struggling Lifts, Underdogs and Big Players. However, 14 % and 17 % in the Nostalgic Lifts and Shadow Existence clusters indicated that they were not implementing any climate change adaptation measures. The reasons for not implementing various adaptation measures are diverse and will be outlined in the following sections. However, general inaction, as mentioned in the interviews, is often attributed to financial constraints and the limited capacity of responsible individuals or operators. Their focus is primarily on maintaining existing equipment, leaving little room for additional investment in adaptation measures.

4.2.2.2. Coping measures. Most popular coping measures include snowmaking, slope maintenance and weather forecasting, all of which are already commonly used by ski areas from almost all clusters, especially by the Struggling Lifts, Underdogs and Big Player. The Shadow Existence and Nostalgic Lifts clusters lag behind the other clusters in terms of snowmaking, slope maintenance and weather forecasting. The reason given in the interviews is the high investment cost for the purchase of grooming vehicles or snowmaking facilities for smaller ski areas (Interviews A, B and C). However, the interview findings imply that the reasons for not implementing coping adaptation measures extend beyond a lack of financial resources. Many ski lifts in these clusters typically consist of only one or two individual lifts, which require minimal operational effort and incur limited costs when not in use. Additionally, these lifts are often operated by local community volunteers:

> *At the moment, our business is being run by the pensioners we have in the club and by a few self-employed people who say okay, 'I'll just be on duty today.'* (Interview C)

As a result, some of these lifts deliberately choose not to invest in adaptation measures. Due to their minimal operating costs, they can afford to remain closed and react flexibly to weather conditions,

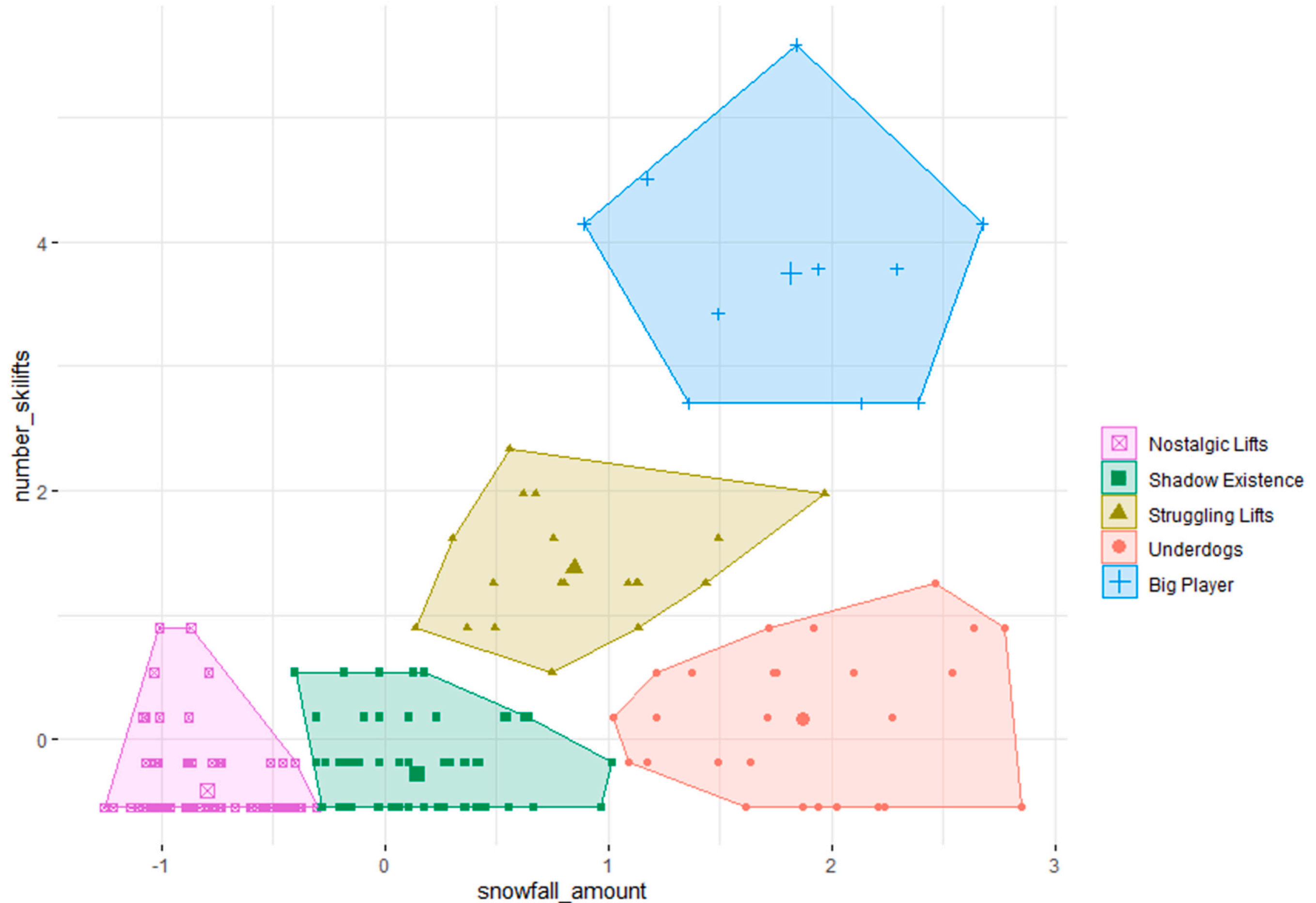

Fig. 2. Cluster plot of the identified ski lifts and ski area clusters in Bavaria
Source: calculation based on data from OpenSkiMap.org (2024), Skiresort.de (2024), and Morin et al. (2020).

operating only when there is sufficient snow without incurring significant expenses if conditions are unfavourable. As one ski operator stated:

> *We don't have to ski. That's our biggest advantage. We don't earn any money from it. As a result, we only run the lift whenever possible.* (Interview A)

One ski operator from the Nostalgic Lifts cluster noted:

> *A commercial operator, as it used to be, will never exist again.* (Interview A)

Nevertheless, these ski areas recognise that skiing is becoming increasingly uneconomical as climate change advances, and their long-term viability is threatened by its impacts:

> *We do it because of this skiing nostalgia. We want to do it for as long as it lasts. And when it's no longer possible, then it's no longer possible.* (Interview A)

Night skiing is a coping adaptation measure that has been widely adopted by at least one-third to half of all surveyed ski areas from all clusters. In the interviews, ski area operators indicated that the implementation of night skiing is relatively straightforward and requires a relatively modest financial input (Interview B). Snow farming has only been implemented by 11 % of the ski areas in the cluster Big Player. Reforestation was implemented in one-third of the Underdogs ski areas, but not at all in the Big Player or Struggling Lifts clusters. Interview comments reveal that the land surrounding ski slopes is often subject to varying land ownership and designated uses, such as alpine pasture management. This leads to highly individualised decisions regarding the feasibility of reforestation next to ski slopes (Interview G). Additional coping measures are rarely planned to be implemented in future.

4.2.2.3. Transitional adaptation. The implementation of transitional adaptation measures is, at best, minimal among all clusters. The role of indoor ski facilities is negligible. Ski area operators noted in interviews that indoor skiing does not align with their mission of bringing people into the mountains and connecting them with nature.

The use of ski mats has begun to be implemented in the Underdogs (17 %) and Big Player (11 %) clusters, while other clusters, such as the snow-limited Struggling Lifts cluster, are still in the planning phase. The interview results suggest that ski mats are perceived as a potentially effective adaptation strategy, demonstrating utility across all clusters, ski area sizes, and climatic conditions. The applicability of these mats extends beyond their primary use on ski slopes; they can also be employed to cover drag lift tracks, which are typically situated at lower altitudes with limited natural snowfall (Interviews C and G).

4.2.2.4. Transformative adaptation. Finally, the implementation of transformative adaptation measures is observed to be of a medium to strong level across the various clusters, except for the Nostalgic Lifts. Especially the Underdogs have already implemented transformative adaptation measures: 67 % offer diverse alternative products to skiing, and 83 % have implemented year-round operations as an adaptation measure. Only 7–15 % of the Nostalgic Lifts implemented an adaptation measure classified as transformative. However, the Nostalgic Lifts and the other clusters demonstrate relatively high rates of planning transformative adaptation measures. Throughout the interviews, most

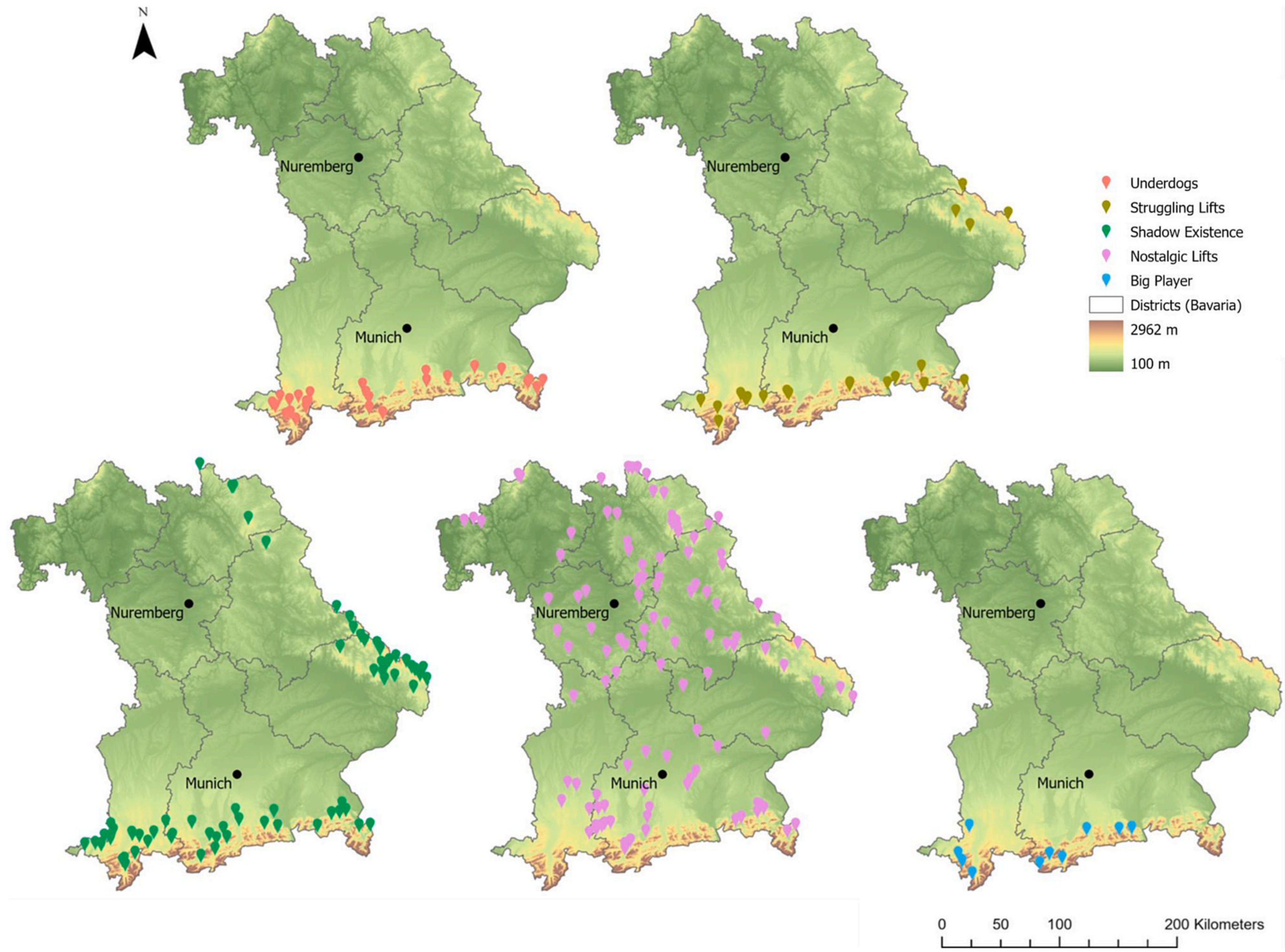

Fig. 3. Spatial distribution of Bavarian ski area clusters
Source: based on data from OpenSkiMap.org (2024), Skiresort.de (2024), Morin et al. (2020), BKG (2024), ESRI (2013).

Table 3
Operational structures by cluster.

Cluster	Number of ski areas per cluster	Participating ski areas in survey (n = 83)	Relative response rate per cluster	Operating structure			
				Private	Municipality	Association	Others
Nostalgic Lifts	115	27	23 %	36 %	18 %	46 %	0 %
Shadow Existence	69	29	42 %	62 %	14 %	24 %	0 %
Struggling Lifts	20	11	55 %	91 %	0 %	0 %	9 %[a]
Underdogs	26	6	23 %	100 %	0 %	0 %	0 %
Big Player	10	9	90 %	100 %	0 %	0 %	0 %

[a] Functional partnership of ski areas.

participants demonstrated an understanding of the importance of year-round operation and product diversification as key adaptation measures. All participants indicated that transformative measures had at least been considered.

4.3. Barriers and drivers to transformative adaptation

In the interviews, no significant differences were found between the clusters regarding their perceived barriers and drivers for transformative adaptation.

Across all clusters, the most frequently cited barriers to year-round operation and product diversification include bureaucratic burdens, conflicts with other interest groups, and the suitability of alternative offers for the target groups. One respondent from the Big Player cluster reported that the ski area has been attempting to have the relevant authorities reactivate abandoned hiking trails with the objective of more effectively distributing the number of visitors and establishing a year-round hiking concept. However, the bureaucratic process has constituted a significant obstacle, with the result that the reactivation has been prevented for years:

> *As I said, it's an existing route that already existed. We are not building anything new. We are also in agreement with the landowners. But the authorisation for this extension to the hiking trail has still not been granted in the second summer (…) (Interview G)*

Interview responses revealed that alternative activities to skiing face

Table 4
Proportion of surveyed ski areas by cluster that have already implemented or planned a specific climate change adaptation measure from the categories of coping, transitional and transformational measures[a].

Adaptation measure	Nostalgic Lifts	Shadow Existence	Struggling Lifts	Underdogs	Big Player
Type: Inaction					
No adaptation measure	**14 %**	**17 %**	**0 %**	**0 %**	**0 %**
Type: Coping measures**					
Slope maintenance	**78 %** / *4 %*	**66 %** / *3 %*	**100 %** / *0 %*	**100 %** / *0 %*	**89 %** / *11 %*
Snowmaking	**48 %**/*4 %*	**24 %**/*0 %*	**82 %**/*0 %*	**67 %**/*0 %*	**89 %**/*0 %*
Weather forecasting	**26 %**/*4 %*	**10 %**/*0 %*	**64 %**/ *0 %*	**50 %**/ *0 %*	**89 %**/ *0 %*
Night skiing	**41 %**/ *18 %*	**34 %** / *14 %*	**45 %** / *9 %*	**50 %** / *0 %*	**33 %** / *22 %*
Reforestation	**7 %**/*0 %*	**21 %**/ *0 %*	**0 %** / *0 %*	**33 %** / *0 %*	**0 %** / *0 %*
Financial incentives and marketing	**0 %**/*4 %*	**3 %**/*3 %*	**18 %** / *18 %*	**0 %** /*0 %*	**22 %** / *11 %*
Snow farming	**0 %**/*0 %*	**0 %**/*3 %*	**0 %**/*0 %*	**0 %**/*0 %*	**11 %**/*0 %*
Type: Transitional adaptation**					
Artificial ski mats	**7 %**/*4 %*	**3 %**/*10 %*	**0 %**/*18 %*	**17 %**/*0 %*	**11 %**/*0 %*
Connecting ski areas	**4 %**/*0 %*	**0 %**/*0 %*	**0 %**/*0 %*	**0 %**/*0 %*	**11 %**/*0 %*
Type: Transformational adaptation					
Year-round operation	**7 %**/*18 %*	**21 %**/*7 %*	**55 %**/*9 %*	**83 %**/*0 %*	**67 %**/*22 %*
Product diversification	**15 %**/*7 %*	**38 %**/*7 %*	**36 %**/*27 %*	**67 %**/*0 %*	**67 %**/*0 %*

*The measures of cloud seeding, expansion of ski areas, roofing over slopes and indoor ski facilities were excluded from the analysis as they are not practiced in Bavaria (partially due to political and legal regulations).
Note: The colours indicate whether an adaptation measure is implemented by less than 25 % (no colour), less than 50 % (light yellow), less than 75 % (light green), or up to 100 % (deep green); or vice versa for inaction.
[a] **Already implemented (bold)**/*planned (italics)*.

challenges in gaining demand-side acceptance. Downhill mountain biking was noted by a participant from the Nostalgic Lifts cluster as not being inclusive for families and challenging for older individuals. In contrast, sledding, which requires no specialised knowledge, training, or equipment beyond a sled, is highlighted as a more accessible alternative, although it still relies on snow (Interview A).

Insights from the interviews indicate that drivers for transformational adaptation are diverse, highly individual, and context-specific. An attractive primary tourism resource (Kaspar, 1998), such as a panoramic mountain view, is of significant importance as a driver for transformative adaptation measures (Interview E). Additionally, secondary tourism resources, including transport infrastructure development and activities like hiking paths and gastronomy, are crucial for showcasing primary resources (Interviews E and G). Good accessibility and a large catchment area also help attract year-round visitors (Interview G). Likewise, the increased desire for nature and activity in mountainous regions, accelerated by the COVID-19 pandemic, has heightened demand for year-round activities, acting as a catalyst for advancing transformative adaptation measures (Interviews C and F).

> *The people want to get out, want to be in nature, want to experience something, want to have something natural again. […] And I also see [the demand] as a given, even if the ski areas cease to exist as such at some point. But there will always be an urge to be active in winter, to experience something in nature, even if it changes, to go snowshoeing, tobogganing or something. So, I'm actually relatively relaxed about it. […] The snowline will inevitably continue to rise. But people will still want to experience something.* (Interview F)

One participant noted that considering the summer tourism concept from the outset of the ropeway's construction has proven advantageous in light of accelerating climate change (Interview G). As indicated by another participant, support programmes that facilitate the transition from winter to summer operations are beneficial (Interview D). Nevertheless, another respondent observed that the minimum investments required for these support programmes are not financially viable for the ski area (Interview B). Participants also mentioned that sharing experiences with other ski areas was a valuable driver for implementing activities (Interview D).

5. Discussion and conclusion

Given the urgent need for climate adaptation in Bavaria's low-altitude ski areas and the call for research on transformative adaptation, this paper examines the status quo of the different types of already implemented or planned adaptation measures. It contributes to the literature by integrating the concept of transformation from climate change studies into research on ski areas and ski lifts, providing a framework to evaluate various adaptation measures for their potential in addressing future climate risks.

5.1. Differences and similarities between clusters

Several potential climate change adaptation measures for ski areas and ski lifts exist beyond snowmaking. By categorising these measures within our proposed framework, we observe that they differ in how much they modify existing regimes and initiate changes that enable ski areas to better manage climate risks. The survey findings further reveal differences between the clusters in terms of the measures that have been implemented or are planned for adapting to climate change.

The Nostalgic Lifts and Shadow Existence clusters, representing over 75 % of Bavaria's ski areas and including those with the lowest snowfall and smallest skiing infrastructure, exhibit a similar adaptation pattern. Up to 17 % of these ski areas do not implement any adaptation measure. Referring to our conceptual framework, these ski areas fall into the inaction category, which literature suggests leads to increased vulnerability (Schipper, 2020) and significant losses (Fedele et al., 2019). Moreover, these two clusters demonstrate relatively low levels of adaptation within the categories of coping measures, transitional adaptation and transformational adaptation.

However, interview findings suggest that the organisational structure of these ski areas can protect them from experiencing significant losses. Many of these ski areas typically feature only one or two lifts, which require minimal operational effort and incur no costs when not in use, allowing them to operate only occasionally when there is sufficient snow. Also, these ski areas are not required to be financially profitable; instead, they are maintained to preserve the local tradition of skiing 'at home', to retain a place for local recreation, and to teach novices and children to ski. A significant number of these ski lifts are operated by part-time workers or even volunteers, which minimises labour costs, while investments and maintenance are supported financially by the municipality or local associations. This finding is similar to a study by Schlegel and Schuck (2024) who identified local support and subsidies as reasons for the survival of isolated lifts and small skiing areas in Switzerland. In this context, these ski areas have unconsciously developed an approach to adapt to climate change 'without adapting'. They can react spontaneously when favourable snow conditions arise, operate independently of financial profitability—which is tied to snowfall and low temperatures—and benefit from strong support from locals who voluntarily run the lifts on weekends. For the example of ski areas from the Nostalgic Lifts and Shadow Existence clusters we therefore disagree with statements in the literature suggesting that inaction eventually leads to increased vulnerability, maladaptation or losses (Fedele et al., 2019; Schipper, 2020).

The situation is different in the other clusters (Struggling Lifts, Underdogs and Big Player) which are primarily organised as companies. On average, these three clusters have developed a more extensive ski infrastructure, characterised by a greater number of ski lifts and longer downhill slopes, and are therefore subject to higher economic obligations compared to the Nostalgic Lifts or the Shadow Existence cluster. Our analysis of key tourism figures demonstrates that, on average, the number of winter overnight stays and tourism intensity across all five clusters is higher than in other non-urban Bavarian municipalities without a ski lift or ski area. However, ski areas in the Struggling Lifts, Underdogs and Big Player clusters are particularly concentrated in municipalities with high winter overnight stays and winter tourism intensity. Moreover, there is a significant correlation between the structural features of the ski areas and the winter overnights stays and the winter tourism intensity of the municipalities in which a ski area is located. While these figures do neither establish a causal relationship between these tourism indicators and the presence of a ski lift or ski area, nor do they account for visitor numbers from day trippers or the local population, the findings still suggest that ski areas in the Struggling Lifts, Underdogs and Big Player clusters play an important role in the winter tourism offerings of their hosting municipalities. However, the considerable overnight stays in the municipalities of the Nostalgic Lift cluster are most likely not causally related to the mostly very small ski areas in this cluster but to other forms of tourism (e.g. health and wellness tourism). In line with the findings of other studies referenced in the review paper by Steiger et al. (2019), or Berard-Chenu et al. (2023) and Abegg et al. (2021), we identified snowmaking as one of the main adaptation measures within the coping measures of these clusters – alongside slope maintenance, weather forecasting, and night skiing.

Results from Bulgaria (Cholakova & Dogramadjieva, 2023), Finland (Haanpää et al., 2015), New Zealand (Hopkins, 2014), Australia (Pickering & Buckley, 2010), and a summary by the IPCC (IPCC, 2023b) suggest that ski areas tend to prioritise short-term measures (coping measures and transitional adaptation) over long-term (transformative) adaptation. Our results partially support these assumptions for Bavaria, as they indicate that coping measures are currently the most important adaptation strategies in the Struggling Lifts, Underdogs and Big Player clusters. Our interview results revealed that the prevalence of these coping measures may be attributed to their relatively straightforward implementation, which aligns with Fedele et al. (2019), who state coping measures do not require significant alterations to the existing system but instead support the status quo.

Contrary to statements in the literature, we found that the planning and implementation of long-term transformative adaptation measures (including year-round operation and/or product diversification) are at a medium to strong level across most clusters, except for Nostalgic Lifts. For this reason, in the case of Bavarian ski areas, we disagree with the literature that ski area operators tend to reject long-term adaptation measures. However, to the best of our knowledge, no other study has assessed the actual implementation of year-round operation or product diversification, making it difficult to compare our results with different spatial contexts.

5.2. The role of already established year-round infrastructure

As previously noted, a considerable share of ski areas was established as transportation options and later adapted for skiing as the sport gained popularity or were designed from the very beginning to serve both for summer and winter recreation. In these cases of the 'ever-popular-mountain ropeways' it is questionable whether emphasising and promoting the longstanding summer operations constitutes a truly transformative step for the operators, even though this development may represent a climate change impacts-driven move. Viewed from this perspective, especially the Bavarian Alps may not have been as vulnerable as other ski destinations, as some of the examined ski areas have not needed to develop year-round operation from scratch. Instead, they have always functioned as year-round destinations due to their higher altitudes (compared to the single lifts in the lowlands and low mountain ranges) and appealing landscape. This interpretation is supported by the fact that overnight stays in the Bavarian Alps were never dominated by the winter season but instead reached a maximum winter share of 38 % in 2004/05 (Job et al., 2014). From 2010 to 2024, apart from the COVID-19 pandemic (2019/20 and 2020/21), the share of winter overnight stays has remained stable between 34 % and 37 %, without reaching a new peak (Bavarian State Office for Statistics, 2025). Moreover, sector representative associations recognise the shift to year-round operation as one of their key sectoral objectives and actively promote this development by advising their members and, in Austria's case, launching a joint marketing campaign for summer ropeways (Fachverband der Seilbahnen Österreichs, 2022; Verband Deutscher Seilbahnen und Schlepplifte e.V, 2024).

5.3. Barriers and drivers to transformative adaptation

Our interviews further indicate that high costs, bureaucratic obstacles, conflicts with other interest groups and landowners, and the suitability of alternative offerings for target guest groups represent the primary barriers to implementing transformative adaptation measures. We found that these barriers are not confined to specific clusters but pose challenges to all ski areas and ski lifts. At this point, further research is required with more participating ski areas to gain a deeper understanding of how to overcome these barriers to transformational adaptation.

In contrast, drivers for transformational adaptation are found to be diverse, often highly individual, and context-specific. In our interviews, we identified the prevalence of an attractive primary tourism resource, such as a panoramic mountain view, and secondary tourism resources, such as the development of transport infrastructure in alpine environments and the availability of activities like hiking trails and dining options, as important factors for the development of year-round operation or product diversification. The financial support provided by the Bavarian government for the modernisation of ski lifts can serve as an important driver for developing year-round operations and diversifying the offered activities. However, an evaluation has shown that this objective has only been partially achieved, as only about half of the subsidised ski lifts are currently in use during the summer (Seibold et al., 2022). Moreover, as our interview findings indicate, the required minimum investment of € 500,000 is too high for many small-scale ski areas, which make up a significant share of Bavaria's ski areas. As a result, these smaller operators are effectively excluded from accessing the programme's funding. Furthermore, the literature suggests that the development of year-round operation and product diversification additionally requires macro-level management, such as communication and marketing efforts, the commercialisation of bundled tourism products at the destination management level, appropriate accommodation options etc. (Klimek & Doctor, 2018).

5.4. Methodological limitations

Our study has several implications for further research. While it provides empirical evidence on the extent of implementation of different types of adaptation in the Bavarian ski industry and presents a framework to distinguish their differing potential in addressing future climate risks, it does not assess the quality of these measures when implemented. The mere implementation of a measure does not guarantee its effective or high-quality execution. Therefore, finding a concept which allows an assessment as well as evaluating the context-dependent effectiveness of each adaptation measure beyond snowmaking remains an avenue for future research (Scott & Gössling, 2022; Tourism Panel on Climate Change, 2023). This is also suggested by Magnan et al. (2020), who argue that positioning a given measure on the maladaptation-adaptation continuum and determining whether it serves as a long-term transformational process or is merely short-sighted is as important as assessing the adaptation measure's potential effectiveness. Furthermore, as outlined by Landauer et al. (2014), findings for specific geographical regions have limited transferability. Implementing adaptation strategies across countries requires caution and careful consideration of local circumstances, such as legal frameworks, geographical conditions and cultural peculiarities that determine the acceptance of adaptation measures.

The climate data used in this study provide a valuable approximation by presenting averages at the NUTS-3 level, differentiated by 100-m altitude increments. Their alignment with topographical features may be limited, particularly when comparing neighbouring ski areas across different NUTS-3 regions. Rather than relying on these values as standalone metrics, our approach focuses on understanding climate data in relation to ski area altitudes and as a basis for clustering our dataset. Future research could enhance precision by incorporating more granular climate data to improve cross-regional comparisons.

We recognise that response rates to the online survey vary between clusters and that results may be subject to response bias, potentially skewed by a higher representation of ski areas actively engaged in climate adaptation. This could lead to a potential overestimation of adaptation efforts in Bavaria. Given the location-specific nature of our findings, they may not be directly generalisable to other ski destinations. However, our methodology—particularly the clustering and categorisation approach—provides a framework for future research to systematically compare the implementation of adaptation measures across different ski tourism destinations and geographic markets.

CRediT authorship contribution statement

Pauline Metzinger: Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jürgen Schmude:** Writing – review & editing, Supervision, Methodology. **Marius Mayer:** Writing – review & editing, Supervision, Investigation, Data curation.

Declaration of competing interest

I have nothing to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jort.2025.100939.

Appendix

Table A1
Overview of climate change adaptation measures for ski lifts and ski areas.

Adaptation measure	Brief description
Reforestation	Planting forests near-by slopes to provide shade and slow down snowmelt.
Roofing over slopes	Installing roofs over ski slopes to protect artificial snow from sunlight.
Snow farming	Storing snow over the summer by piling it under insulating material.
Snowmaking	Using snow cannons and lances to produce artificial snow.
Cloud seeding	A weather modification technology from agriculture used to generate additional precipitation in the form of snow.
Slope maintenance	Everyday grooming of slopes to enable skiing on smoother surfaces with thinner layers of snow; partially technology-assisted (e.g. snow measurement for more effective slope maintenance)
Artificial ski mats	Weather-independent plastic mats that simulate snow and can be laid on existing slopes or lift routes.
Indoor ski facilities	Allowing year-round skiing under controlled conditions within an indoor facility.
Weather forecasting	Using forecasts to better determine the timing of the ski season opening.
Connecting ski areas	Supplementing/connecting existing ski areas with snow-reliable ski areas in the same ski destination
Expanding ski areas	Developing the ski area by expanding to new areas at higher elevations and on north-facing slopes.
Product diversification	Counteracting winter snow shortages with alternative activities such as indoor swimming pools, wellness centres, guided or marked winter hikes, husky tours, animal walks, concerts, fitness centres, restaurants, and retail shops etc.
Financial incentives	Stabilising booking numbers despite weather risks with dynamic, weather-dependent ticket pricing.
Year-round operation	Creating offerings that attract visitors in both summer and winter, such as using ski lifts for mountain biking or hiking outside the ski season.
Night skiing	Maximising slope usage time by offering skiing in the evenings under good conditions.

Source: based on literature review.

Table A2
Interview participants (ski area operators) from ski areas across all clusters and the ski area's structural and climate variables.

Code	Cluster	Duration	Structural variables: length of slopes, number of lifts	Climate variables: snow precipitation amount, days above threshold (2021–2040/ RCP4.5)
A	Nostalgic Lifts	01:07 h	.6 km, 2 lifts	128 cm, 8 days
B	Shadow Existence	00:31 h	1.8 km, 3 lifts	260 cm, 45 days
C	Nostalgic Lifts	00:25 h	.5 km, 1 lift	84 cm, 5 days
D	Struggling Lifts	00:29 h	8 km, 9 lifts	263 cm, 67 days
E	Struggling Lifts	00:40 h	11.5 km, 6 lifts	330 cm, 77 days
F	Underdogs	00:37 h	6 km, 2 lifts	253 cm, 81 days
G	Big Player	00:46 h	30 km, 15 lifts	341 cm, 82 days

Source: based on data from OpenSkiMap.org (2024); Skiresort.de (2024) and Morin et al. (2020).

Data availability

Data will be made available on request.

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